Figure 9a illustrates a tank circuit in which a variable inductor acts as the frequency tuning element;

Figure 9b illustrates a current feedback arrangement for implementing the variable inductor of Figure 9a;

Figure 10a illustrates a binary weighted switched capacitor bank for implementing the variable capacitor of Figure 8a;

Figure 10b illustrates a binary weighted switched inductor bank for implementing the variable inductor of Figure 9a;

Figure 11 illustrates a radio frequency circuit in a direct conversion receiver using a tuning arrangement according to the invention;

Figure 12 illustrates a tuning arrangement using DSP controlled tuning; and

Figure 13 is a schematic diagram of a programmable tunable filter.

Detailed Description

Figure 1 shows a conventional tank circuit 1 having a capacitor 2 and an inductor 3 in parallel. In the ideal tank circuit shown, excited by a source 4, energy flows back and forth between the capacitor and the inductor with no losses, the resonant frequency f_0 of the circuit being given by the equation:

$$f_0 = 1/2\pi\sqrt{(LC)}$$

However, in a practical LC tank circuit, energy is lost due to parasitic resistance in the capacitor and the inductor, which can be modelled as a parallel resistance R_P 5 in the equivalent circuit shown in Figure 2.

An active circuit can be constructed, using transistors, which exhibits opposite behaviour to that of a resistor. Such a circuit is referred to herein as a loss compensation or negative resistance circuit and can be modelled as $-R_N$ 6 in the equivalent circuit shown in Figure 3.

An example loss compensation/negative resistance arrangement $-R_N$ 6 using a cross-coupled transistor pair M1, M2 with tail-current (I) biasing, is illustrated in Figure 4.

Referring again to Figure 3, when $R_N = R_P$, the two resistors in parallel provide an effective open circuit, so that the negative resistance compensates for the energy losses in the tank circuit, causing the circuit to behave as an oscillator. If R_P is not entirely compensated for, the tank circuit 1 has losses and acts as a bandpass filter, the frequency response of which is shown in Figure 5, illustrating that the filter has a center frequency f_0, which can be shown to be the same as the resonant frequency of the tank circuit.

Referring to Figure 6, a tunable filter arrangement in accordance with the invention comprises a tunable filter 10 including an LC tank together with a compensation circuit 11, for example a negative resistance circuit. The filter 10 receives an input signal S via an isolator 12, for example a switch for isolating the filter 10 from the input signal. Both the isolator 12 and compensation circuit 11 receive a tuning control signal. The output of the filter 10 is connected to a frequency comparator 13 which produces a tuning signal which adjusts the resonant frequency of the filter circuit 10. A sample and hold circuit 14 is arranged to store the tuning signal once the desired frequency is achieved. The operation of the system of Figure 6 will now be described in detail with reference to Figure 7.

Referring to Figure 7, when a tuning cycle is to commence, a tuning control signal is set (step s1) to isolate the filter 10 from the input signal S via the isolator 12 (step s2) and to activate the compensation circuit 11 (step s3), so converting the filter 10 into an oscillator. The oscillator 10 then oscillates at the resonant frequency set by the tank circuit's reactive components. The output of the tunable filter circuit acting as an oscillator 10 is fed to the frequency comparator circuit 13 (step s4). This compares the output frequency with a desired or reference frequency (step s5) and outputs a tuning signal to alter the resonant frequency of the filter 10 towards the desired frequency (step s6). The resonant frequency is tuned by any one of a number of techniques which will be described below, usually involving the use of the tuning signal to alter a tunable element such as the capacitance of the tank circuit. Once the desired resonant frequency has been achieved, the tuning signal is sampled in the analog or digital domain and held so that it can be continuously

applied to the tunable element (step s7). The tuning control signal is then released (step s8), resulting in deactivation of the compensation circuit 12 (step s9), so turning the oscillator back into a bandpass filter 10. The release of the tuning control signal also causes the input signal to the bandpass filter 10 to be restored (step s10).

Tuning of the filter/oscillator 10 can be achieved in a number of ways. Some of the many possible arrangements are illustrated in Figure 8. Figure 8a illustrates a basic tank circuit in which a variable capacitor 15 acts as the frequency tuning element. The variable capacitor can be implemented as a MOS varactor, as shown in Figure 8b, or as a diode varactor shown in Figure 8c. An alternative to varactor tuning is to provide active circuitry to provide feedback. For example, Figure 8d illustrates the well-known Miller capacitance arrangement which uses negative feedback to alter the effective value of a linear capacitor.

In an alternative embodiment, the inductor 16 in the tank circuit can be the tunable element, as illustrated in Figure 9a. A variable inductor can be implemented by the current feedback arrangement shown in Figure 9b, by analogy with the Miller capacitance shown in Figure 8d.

As an alternative to the tunable element arrangements shown in Figures 8 and 9, tuning can be implemented by switching passive elements such as capacitors and inductors in or out of an LC circuit. Figure 10a illustrates a binary weighted switched capacitor bank and Figure 10b illustrates a binary weighted switched inductor bank. By switching one or more components in or out of the filter circuit under the control of the tuning signal V_{ctrl}, a desired frequency range can be covered with a resolution set by the smallest unit element.

Figures 11 and 12 illustrate two systems which use existing circuitry in an RF receiver to simplify the tuning system according to the invention. Figure 11 illustrates a radio frequency circuit in a direct conversion receiver 20, implemented for example by an application specific integrated circuit (ASIC). The circuit includes an RF receiver chain comprising a low noise amplifier LNA 21, a bandpass